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(54) Method for producing a large arcuate tank and a tank produced by the method.

(57) A large arcuate vessel is produced by welding commercially available large plane metal plates (1a, 1b, 1c) together to form a composite plane plate blank (1), cutting the composite plane plate blank to a shape adaptable to the desired arcuate tank surface, and thereafter shaping the plate blank to the required arcuate form preferably by heat forming.

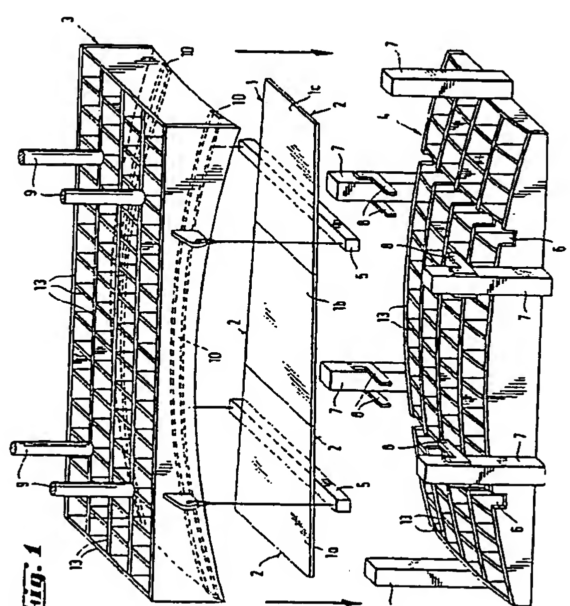

Fig. 1

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This invention relates to a method for producing a large arcuate tank and to a tank produced according to the method. Throughout this specification, the term "arcuate" should be taken to mean having the form of all or any portion of the surface of a sphere.

The temperature of Liquefied Natural Gas (LNG) is about -163°C. This places special demands on the choice of material for a tank in which LNG is stored, on the design of the tank and on the method used for producing the tank. Further, a tank for containing LNG should be self-supporting in order to minimize transfer of heat to the contents of the tank. The cross-section (e.g. diameter) of a large arcuate LNG-tank is about 40 m. A tank suitable for transport and storing of LNG is usually also suitable for transport and storing of other fluids, provided that the pressure inside the tank is not excessive. Because the use of tanks for transport and storing of LNG places stricter demands, the invention is described in the following with reference to the demands placed explicitly by LNG, but this does not exclude the application of the invention to tanks for other suitable fluid contents.

An LNG-tank is preferably made of aluminium plates, because the extremely low temperature does not deleteriously affect the strength of aluminium. Alternatively, however, special steel alloys can be used for tank panels, but this is noticeably more expensive and forming a steel plate to arcuate form is more difficult than forming an aluminium plate to arcuate form.

Any point on an arcuate surface can arbitrarily be designated as a pole. Knowing the radius of curvature of the arcuate surface, it is possible to define lines of longitude and latitude of the arcuate surface relative to the pole.

Planar, rectangular plates suitable for use in the construction of arcuate tanks are commercially available from various sources. The largest such plate available from a particular source will, for convenience, be referred to herein as a "standard metal plate". Such a standard metal plate would be made by rolling to provide a unitary piece which is essentially homogeneous in composition. Even the largest commercially available standard metal plate suitable for construction of an arcuate tank is rather small in size relative to the surface area of a large arcuate tank. Accordingly at least about 100 such standard metal plates are typically needed to construct a large arcuate tank.

Traditionally, a large arcuate tank is assembled from commercially available standard metal plates by cutting each standard metal plate to the desired peripheral shape to form a plate blank, bending the plate blank to arcuate form, and welding the arcuate plate blanks together edge-to-edge. This procedure is very demanding, because it is difficult to ensure that the bent plate blanks are of the correct arcuate shape, and deviations from the intended arcuate form affect the welding procedure. Furthermore, handling procedures are noticeably more difficult when dealing with an arcuate workpiece than when dealing with a plane workpiece. More importantly, however, is the fact that it is difficult to weld arcuate plates together and the smaller the plate blanks are, the more welding joints there must be between arcuate plates.

US-A-3938363 discloses a method of forming a plate to arcuate form employing a mould that comprises a lower convex die and an upper concave die. In accordance with that method, a plate of aluminium alloy is heated to a temperature of about 500°C and is placed over the lower die. The upper die is lowered onto the hot aluminium plate, and the weight of the upper die causes the plate to be formed to the desired curvature.

The lower die disclosed in US-A-3938363 is constructed of a framework of steel plates defining rectangular cells, and the cells are filled with a refractory compound. The upper surface of the refractory compound filling the cells of the lower die is screeded to arcuate form, the upper surface of the refractory material being approximately 5 cm above the upper edges of the steel plates defining the cells. The concave die is of the same general cell-filled construction as the convex die and is made using the convex die as a mould.

One aim of the invention is to reduce the number of operations involving handling of arcuate plates when assembling large arcuate tanks.

What constitutes the invention in its broadest aspect is defined in the following claim 1.

Desirably, part or all of the largest available standard metal plates are welded together in planar form to form a considerably larger composite plate. When welding the plates (or plate portions) together, conventional techniques can be used. The area of the composite plate is several, preferably at least three, times the area of a large standard metal plate. If not of the required shape after welding, the composite plate is cut to form a large plate blank of which the peripheral form is such that once it has been bent to arcuate form it will fit the plate pattern selected for the arcuate tank without any further cutting. For example, the plane plate blank may be made or cut so that its edges will define lines of longitude and latitude in the eventual arcuate tank. In this fashion, the plate blank is adapted to facilitate construction of an arcuate tank. Only after the welding together of sub-plates to create the large plate blank is the latter bent into arcuate form, whereafter it can be used without further machining as a portion of an arcuate tank. In this manner the number and length of welding joints necessary for welding together arcuate workpieces are reduced noticeably, which substantially reduces the production costs of an arcuate tank.

If the large plate blank made in the first step is so formed, that its length and width are substantially

equal, a particularly convenient production method results. The result is, of course, dependent on the dimensions of the standard metal plates, so "substantially equal" may also encompass a difference between length and width of several metres. It has been established as being particularly convenient if the large plane plate blank assembled by welding has a size of about 100 m². Of course, the aim is to produce as large a plane plate blank as possible, but if the plate blank size is substantially larger than 100 m², bending it to arcuate form may involve unreasonably heavy costs.

Before curving the large plane plate blank to arcuate form, it may be provided with edge bevellings required to facilitate a later welding phase since such edge forming is more easily carried out on a plane plate blank than on an arcuate plate blank.

The shaping of the plane plate blank into arcuate form is, in the case of the preferred aluminium plates, conveniently carried out by heat forming at a temperature in the range of 350 to 460°C and more conveniently the forming temperature is in the range 400 to 430°C. In the latter of these temperature ranges, an aluminium plate suitable for the construction of an arcuate tank can be bent into arcuate form in a fairly simple device.

The heat forming may be performed using an oven that encloses the large plane plate blank and its forming device. The oven is conveniently positioned by lowering it over the forming device. When the plate blank has reached the desired temperature within the oven space, it should be kept constantly under forming pressure for about an hour, preferably for about two hours. In this way an effective forming is achieved and the tensions caused by the forming are evened out.

A mould for applying forming pressure to the large plane plate blank may be formed of convex and concave dies, which serve as forming tools between which the plate blank is shaped into arcuate form. Each die may consist of plates placed on edge to form an open grid, in which the edges of the plates forming the grid determine the desired arcuate shape of the die. It is preferred that each plate of the convex die and a counterpart plate in the concave die be made by cutting an arcuate slot in a single large plate. The width of the slot should correspond at least approximately to the thickness of the plate blanks that are to be bent during use of the mould. The slot in each plate can be interrupted by short bridges which hold together the two parts of the plate, at opposite respective sides of the slot. Two groups of plates can be provided, one group to be used as longitudinal plates of the two grids and one group to be used as the transverse plates of the two grids. The spacing apart of the bridges in the longitudinal plates is conveniently between 1 and 2 metres. In the transverse plates the spacing is conveniently such that there will be two bridges between each two adjacent longitudinal plates when the grid has been assembled. The longitudinal plates are conveniently used as such for forming the grid but the transverse plates are suitably cut into pieces for fitting as transverse inserts into the grid, each with two bridges in the arcuate slot. The slot in each plate is partcircular and each slot has its own specific radius of curvature required for giving the dies the required arcuate shape. The bridges can be quite short, each about 3 cm long.

The longitudinal and transverse plates are assembled to form a grid and are welded together at each of the grid's intersections. The bridges are then cut, thereby separating the grid structure into a grid for a convex die and a grid for a concave die. In this manner, a perfect mutual fit of the two dies is achieved, and very little plate material goes to scrap. It is important that the means for forming the plate blanks is not made so expensive that the costs of the means add substantially to the costs of the arcuate tank, thus offsetting the saving that arises from reducing the length of welding joints which are needed between arcuate plates.

A forming die produced in this manner is relatively inexpensive, because the desired arcuate form is created by cutting a relatively small number of plates along an arcuate curve, which is quite an easy procedure. The pitch of the die grid may be relatively large. For instance, the distance between the plates may be over half a metre. In the regions of the die at which at least one edge of the large plate blank will be located, it is advisable to arrange, at least on the arcuate face of the concave die, an additional support member that does not conform to the grid pattern of the die but spans across the interstices in the grid, because otherwise the said at least one edge region of the plate blank may not be formed effectively and uniformly enough, but may be left slightly undulating, which is a considerable disadvantage when the plate blanks of arcuate form are to be joined together by welding.

Generally, the required forming force can easily be produced by means of gravitational forces due to the weight of the upper die. Should this weight be inadequate, additional weight can be added during the forming phase or one may use, for instance, hydraulic means for increasing the downward directed force. Using additional weight is, however, a simple and inexpensive solution. If additional weights are used, it is convenient to arrange for the additional weights to be located outside the oven space and to act on the upper die from there. In this way no heat energy is wasted in warming up the additional weights, and further, the forming force can easily be controlled from outside the oven space. Further, since the mould and the plate are heated concurrently in the oven, it is easy to ensure that the plate is at a uniform temperature when the forming force is applied. Moreover,

the undesirable possibility of local cooling of the plate due to its being brought into contact with a relatively cold die is avoided.

The invention also relates to an LNG-tank or the like which is produced by applying the described methods.

The invention will now be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 schematically shows a mould and how a large plate blank that is to be bent to arcuate form may be positioned in the mould,

Figure 2 schematically shows the mould in an oven space,

Figures 3A, 3B and 3C illustrate constructional features of the mould,

Figure 4 illustrates a production line for heat-shaping large plate blanks to arcuate form, employing both a forming oven and a cooling oven,

Figure 5 is a plan view of a die used in the cooling oven of Figure 4, and

Figure 6 is a sectional view taken on the line VI-VI of Figure 5.

In the drawings, numeral 1 indicates a large composite plate blank assembled by welding together three standard metal plates 1a, 1b and 1c. The plate blank 1 is shown in the drawing with an elongated shape, but this is only because the preferred, almost square shape, is more difficult to show in perspective. The plate blank 1 is destined to later form part of a spherical surface, and therefore its edges 2 are slightly curved. The edges 2 of the plate blank are machined, typically bevelled, to form a suitable groove for a weld joint that will be formed in a later welding operation.

Above the plate blank 1 is an upper die 3 with a concave lower surface and below it is a lower die 4 with a convex upper surface which is supported by a plane base (not shown). The upper die 3 is moved into position by a crane and during this transfer the plate blank 1 is supported by supporting beams 5 depending from the upper die 3. After the forming operation, the curved plate blank 1 is lifted up by means of the same supporting beams. The supporting beams 5 are received in apertures 6 in the upper surface of the lower die 4 so that they do not interfere with the shaping of the plate blank 1.

Several guide posts 7 are located around the lower die 4, for guiding the upper die during a pressing operation. Some of the posts 7 have a releasable support element 8, which temporarily supports the upper die 3 in a first positioning stage. During this stage, the plate blank 1 rests on top of the lower die 4 without load. Next, an oven, described in more detail with reference to Figure 2, is placed with a crane over the dies 3 and 4 and the plate blank is heated. When the required forming temperature has been uniformly attained over the plate blank 1, the supporting elements 8 are released, whereby the weight of the upper die 3 is freed to act on the plate blank 1. Should this weight not be sufficient to achieve the required forming operation in a reasonable time, the upper die may be loaded with additional weight, which could be, for instance, one or more steel plates which are placed on loading posts 9 attached to the die 3.

As shown in Figure 1, the dies 3 and 4 are each made from a grid of plates so that the respective concave and convex edges of the grid walls 13 determine the required part-spherical form. A forming die built in this way, where the pitch of the grid walls 13 is of the order of half a metre, is not very expensive in spite of its large dimensions. Because the die grid will not normally precisely correspond to the dimensions of the plate blank, additional supporting members 10 are needed, at least in the concave die 3, to define at least one of the edge regions of the plate blank 1.

Figure 2 shows the oven 11 located over the dies 3 and 4. The oven can be a simple thermally insulated box-like construction provided with necessary heating devices. The load posts 9 of the upper die pass through clearance holes in the top of the oven so that any additional weight 12 that is eventually placed on them is transmitted through the top of the oven although the additional weight remains outside the oven space. Using the load posts 9, the upper die 3 can be raised and lowered while it is in the oven space, which is necessary in order to release the supporting elements 8 and lower the upper die 4 into its forming position. Figure 2 shows one supporting element 8 on one guide post 7 of the lower die in its released position, in which it is not supporting the upper die 3.

Figures 3A, 3B and 3C show how the mould may be constructed from two sets of plates, longitudinal plates 20 and transverse plates 21, each provided with an arcuate slot 24. The slots 24 are each interrupted by short bridges 26 at spaced intervals therealong. The width of each slot 24 corresponds approximately to the thickness of the plate blank that is to be bent using the mould.

The transverse plates 21 are cut into transverse inserts 21a, each having two bridges 26 in their arcuate slot 24. The longitudinal plates 20 and the inserts 21a are fitted together to form a grid within an outer enclosure defined by plates 28 also provided with the same kind of arcuate slot 24. The plates 20 and the inserts 21a are securely welded together at each of the grid's intersections 23 and the bridges 26 are then cut, separating the grid into two portions that form the basis for the concave and convex dies respectively.

In the production line shown in Figure 4, a separate cooling oven 30 is arranged in line with a forming oven 11 generally of the type shown in Figure 2. The two ovens are stationary and each has two sliding doors 34 at opposite respective ends. Two concave upper dies 3a, 3b are located in the forming oven 11

and the cooling oven 30 respectively. The corresponding convex dies 4a and 4b are mounted on respective transport carriages 32a and 32b which are each connected to a respective driving cable running in a loop from one of two winding drums 33 over a pulley (not shown) and back to the respective drum 33. Each carriage is driven backwards and forwards into and out of the oven(s) by the respective winding drum. Each oven is provided with a mechanism for raising and lowering the concave die and for raising and lowering the plate blank relative to the convex die. The dies are each about 12 m by 9 m when viewed in plan with the grid plates at a pitch of about 60 cm.

In operation of the production line illustrated in Figure 4, the first plane plate blank is placed on the convex die 4a carried by the carriage 32a, and the die 4a and the plate blank are moved into the oven 11. The plate blank is bent to part-spherical form in the manner described with reference to Figures 1 and 2, the concave die 3a is raised and the formed plate is lifted from the convex die 4a by use of supporting beams, as described with reference to Figures 1 and 2. The carriage 32a with the die 4a then returns to its initial position and the carriage 32b with the die 4b, which is identical to the die 4a, takes its place inside the oven 11. The formed plate blank is lowered onto the convex die 4b and the carriage 32b carries the die 4b and the formed plate blank into the cooling oven 30, where the plate blank is pressed between the concave die 3b and the convex die 4b during controlled cooling for about two hours. The concave die 3b is then raised and the carriage 32b carries the convex die 4b and the cooled, formed plate blank from the cooling oven 30. During the cooling of the first plate blank in the cooling oven, a second plate blank is bent to arcuate form in the forming oven 11 by use of the dies 3a and 4a.

Air supply ducts 36a, 36b and 36c are installed in one wall of the cooling oven 30, and air is delivered to these ducts by means of fans (not shown) through controllable throttles 46a, 46b and 46c. The air supply ducts are each 250 mm in diameter and the air flow through each air supply duct is about 1 cubic metre per second. When the carriage 32b is positioned in the oven 30, the ducts 36a, 36b and 36c register with extension ducts 48a, 48b and 48c, respectively (250 mm diameter), which extend through passages formed in the die 4b by holes 38 in the grid plates. The ducts 48a, 48b and 48c are connected to further air distribution ducts 36d of 200 and then 125 mm diameter. Each duct 36d extends generally horizontally and passes through at least one cell of the die 4b, and is provided with a vertical outlet tube 36e (50 mm diameter) in each cell through which it passes, as shown in Figure 6.

The outlet tubes 36e debouch below the formed plate, and each is provided at its upper end with a spreading member 44 for distributing the flow of air leaving the outlet tube. Air escapes from the lower die 4b through the holes 38 and is vented to atmosphere. The three duct systems, connected to the ducts 36a, 36b, 36c respectively, are separate and separately controllable. Arrows 42 show the air flow direction.

Controlled cooling means that the cooling is controlled in response to the temperature of the plate blank. Thus, temperature probes are provided for continuously measuring the temperature of the plate at selected measurement points 40, and at each measurement point 40, the temperature is measured separately on each of the two opposite sides of the plate 1. Operation of the fans for supplying air to the lower die is controlled in response to the temperature values determined, so that the temperature at each measurement point follows a selected function of time during the cooling operation. Normally, three double-sided temperature measurement points are sufficient, one in the central area of the plate and one each at two diagonally opposite corner areas, as shown by the numerals 40 in Figure 5.

The production line shown in Figure 4 provides the advantage that the forming oven 11 and the die 3a are not cooled when the plate blank is cooled, and accordingly energy for heating the oven 11 and the die 3a is saved. By holding the blank in the proper part-spherical shape during controlled cooling, it is ensured that the blank will remain of the proper shape when the holding force is removed.

The invention is not limited to the method that has been described and explained, since several modifications thereof are feasible within the scope of the following claims. For example, the invention is not restricted to the entire tank being spherical and may be applied to a tank composed of two hemispherical portions joined by a cylindrical portion.

Claims

1. A method for producing a large arcuate tank suitable for LNG-storage by welding together arcuate plates, **characterised in that** a plane plate blank (1) is created by welding together plane standard metal plates, or portions of such plane plates (1a, 1b, 1c) to form a composite plane plate of which the area is substantially greater than that of a single standard metal plate, cutting the composite plate to give it a peripheral shape suitable for adaptation to an arcuate surface and thus form a composite plane plate blank (1) and thereafter forming the composite plane plate blank (1) to an arcuate form usable as such as a portion of the arcuate tank.

2. A method according to claim 1, **characterised in that** the composite plane plate blank (1) has a length and width that are substantially equal.

3. A method according to claim 1 or 2, **characterised in that** the composite plane plate blank (1) has an area of about 100 m^2.

4. A method according to any one of the preceding claims, **characterised in that** before the composite plate is formed into arcuate form, it is provided with edge bevellings or the like that facilitate a later welding stage in the production of the tank.

5. A method according to any one of the preceding claims using aluminium plates (1a, 1b, 1c) for the composite plane plate blank (1), **characterised in that** the forming of the composite plate into arcuate form is carried out by heat forming at a temperature which is in the range 350 to 460°C, preferably in the range 400 to 430°C.

6. A method according to claim 5, **characterised in that** the heat forming takes place in an oven space (11), in which the composite plate is, when the required forming temperature has been attained, held under forming pressure for about one hour, preferably for about two hours.

7. A method according to claim 5 or 6, **characterised in that** the composite plate is heat formed between a convex die (4) and a concave die (3), each of which has the general form of an open grid, the edges of the grid walls (13) determining the desired forming shape.

8. A method according to claim 7, **characterised in that** in each die adjacent grid walls (13) are about half a metre apart.

9. A method according to claim 7 or 8, **characterised in that** in a position corresponding to at least one edge area of the composite plate there is, at least in the concave die (3), an additional support surface (10) extending across the interstices of the grid defining the die.

10. A method according to any of claims 5 to 9, **characterised in that** the required forming force is accomplished by using gravitational forces generated by virtue of the weight of the upper die (3) possibly augmented by an additional weight-loading (12) of the die.

11. A method according to claim 10, **characterised in that** the additional weight-loading (12) of the upper die (3) is effected by weights located outside the oven space (11).

12. A method according to any one of claims 5 to 11, **characterised in that** following heat forming, the composite plate (1) is cooled while subjected to pressure between a concave die (3b) and a convex die (4b).

13. A method according to claim 12, **characterised in that** the cooling is effected in a cooling oven (30) disposed downstream of an oven space (11), in that each oven has its own convex die (4a, 4b) and in that the convex die (4b) for the cooling oven (30) moves into the oven space (11) to collect a hot formed composite plate (1) therefrom.

14. A method according to claim 12 or claim 13, **characterised in that** the or each convex die (4) is located on a carriage (32) and in that a composite plane plate for heat forming is located on a hot convex die (4a) upstream of the oven space (11) and is carried into the oven space on said carriage-mounted convex die (4a).

15. A method of manufacturing a mould suitable for use in any one of claims 1 to 14 for forming a composite plate to arcuate form, **characterised in that** said method comprises
(a) providing first and second sets of mould plates (20, 21), each mould plate being formed with an arcuate slot (24) having slot-interrupting bridges (26), whereby the slot effectively divides each plate (20, 21) into a first portion, towards which the arcuate slot (24) is convex, and a second portion, towards which the arcuate slot is concave,
(b) fitting the first (20) and second (21) sets of plates together as a grid, the plates (20) of the first set being substantially parallel to each other and the plates (21) of the second set being substantially perpendicular to the plates of the first set, the plates being positioned such that the slots (24) lie on the same arcuate surface,
(c) securing the plates (20, 21) together, and
(d) removing the bridges (26) from the slot (24) of each plate (20, 21).

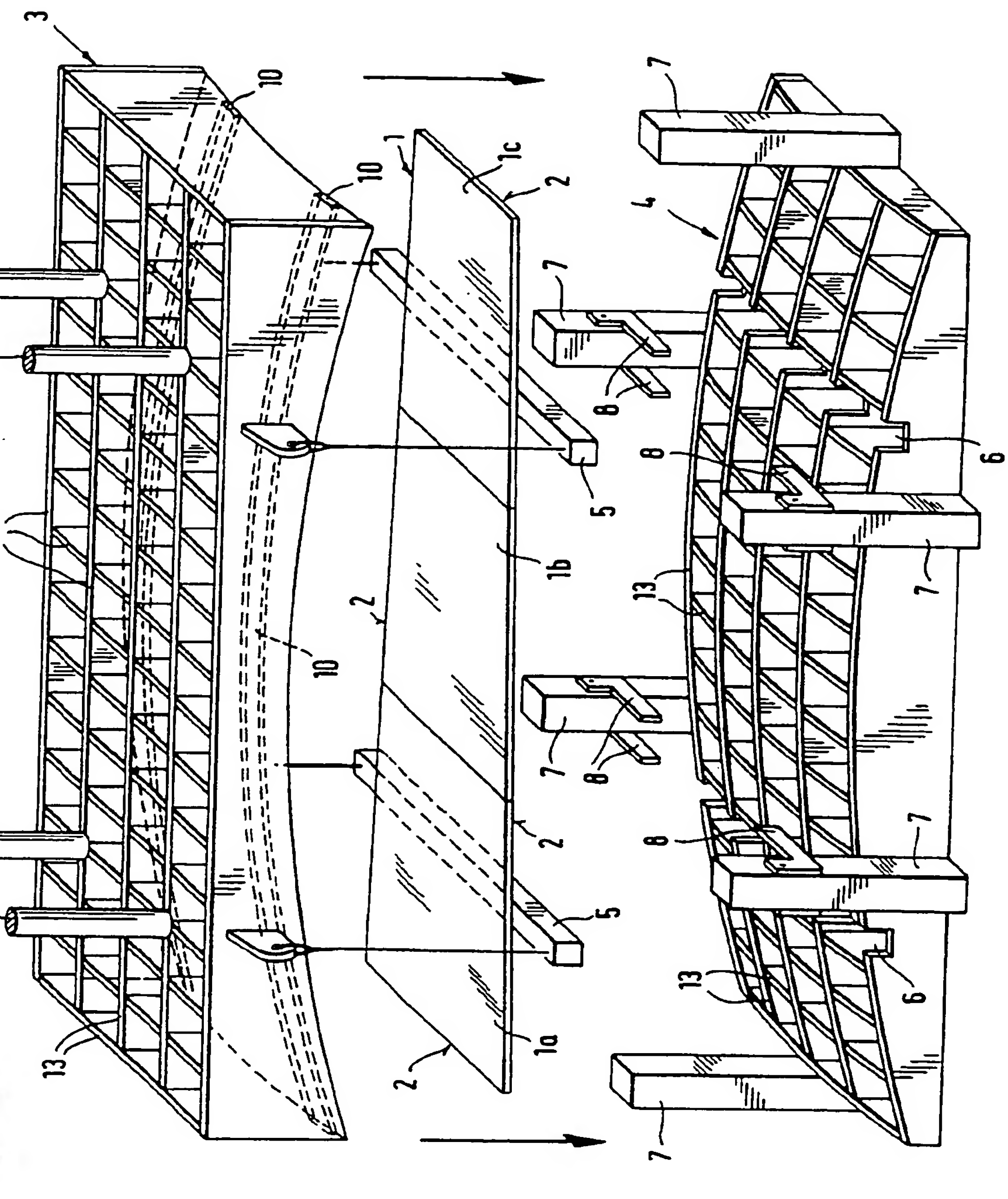

Fig. 1

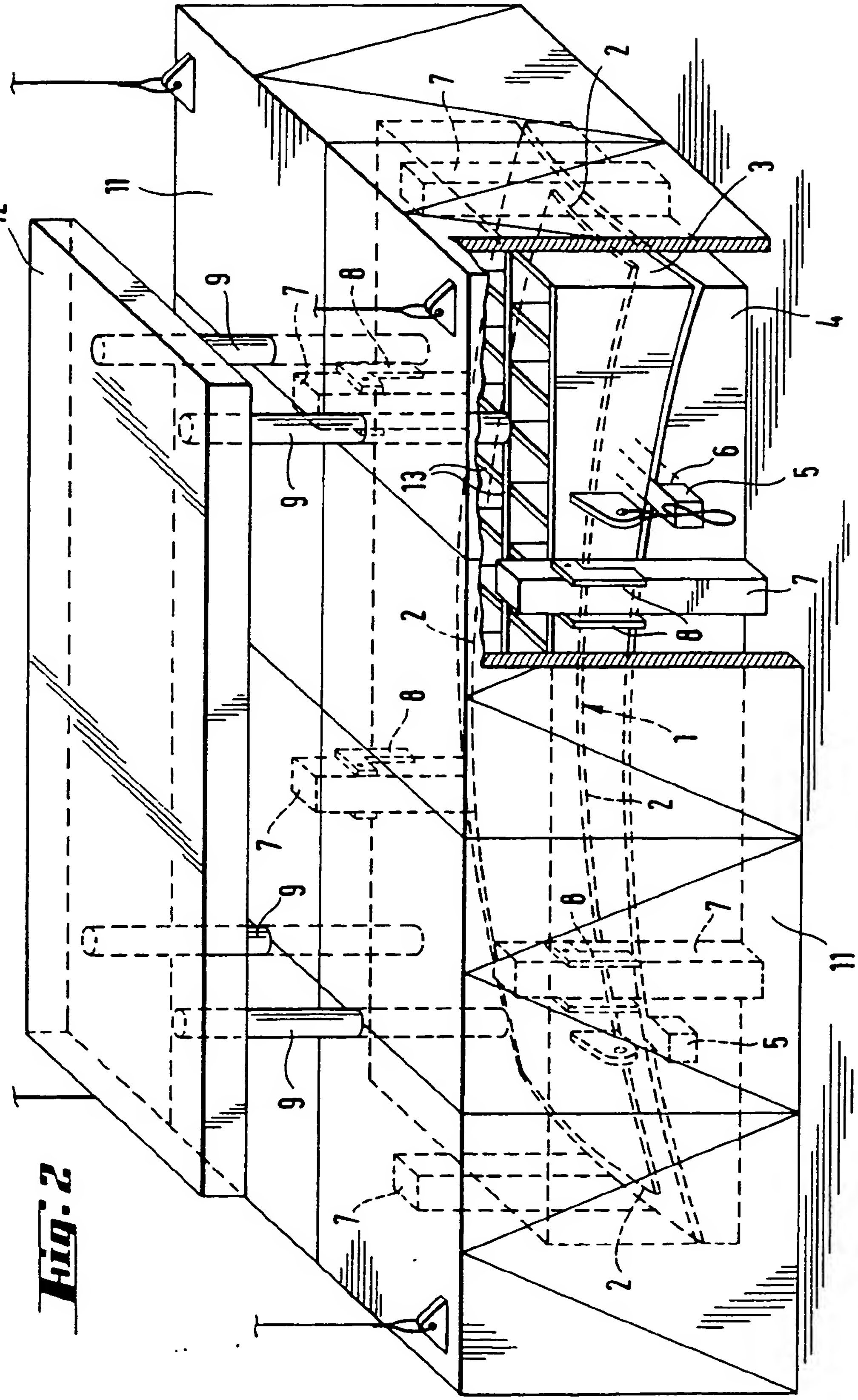

Fig. 2

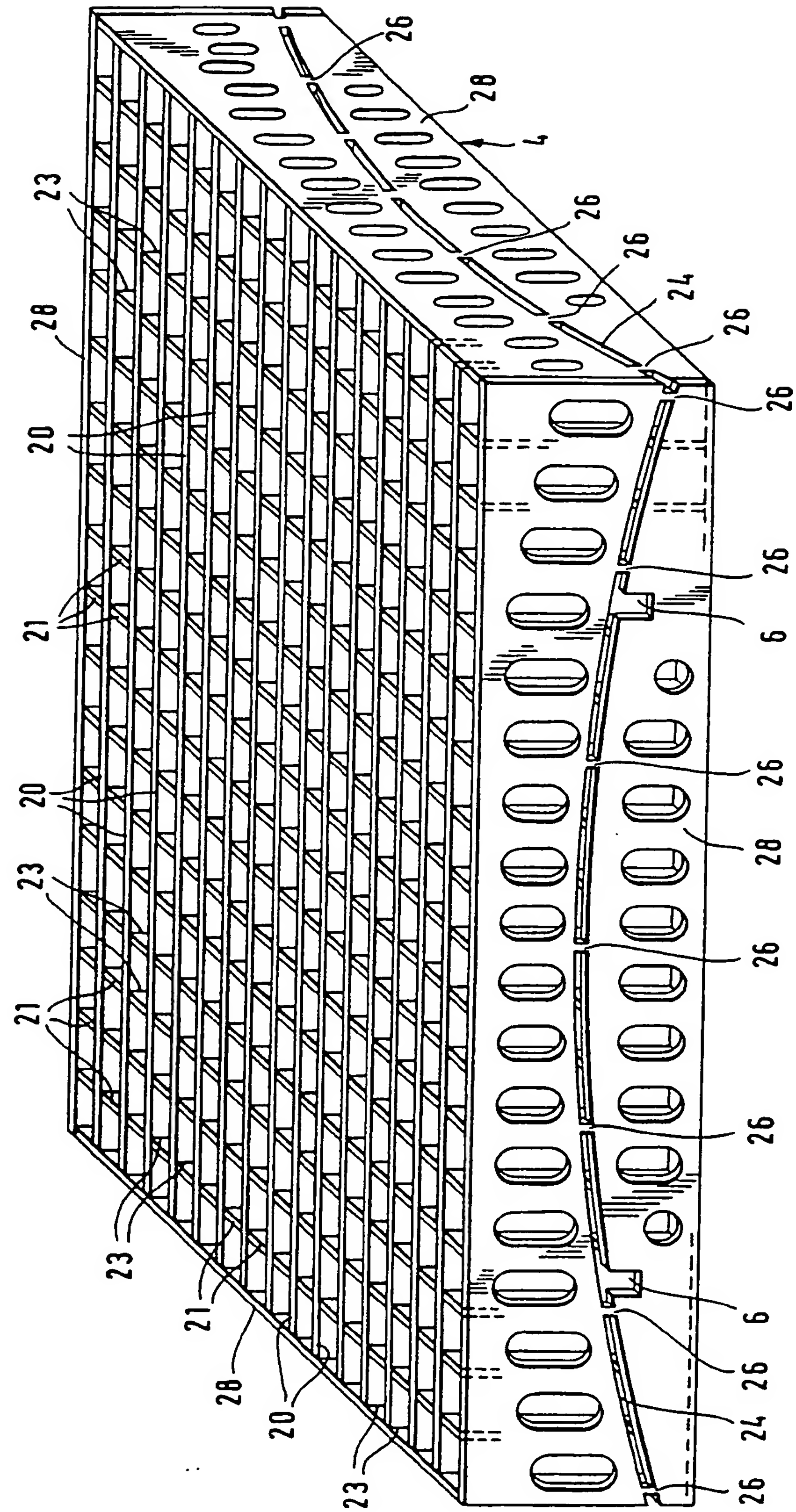
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Fig. 3A

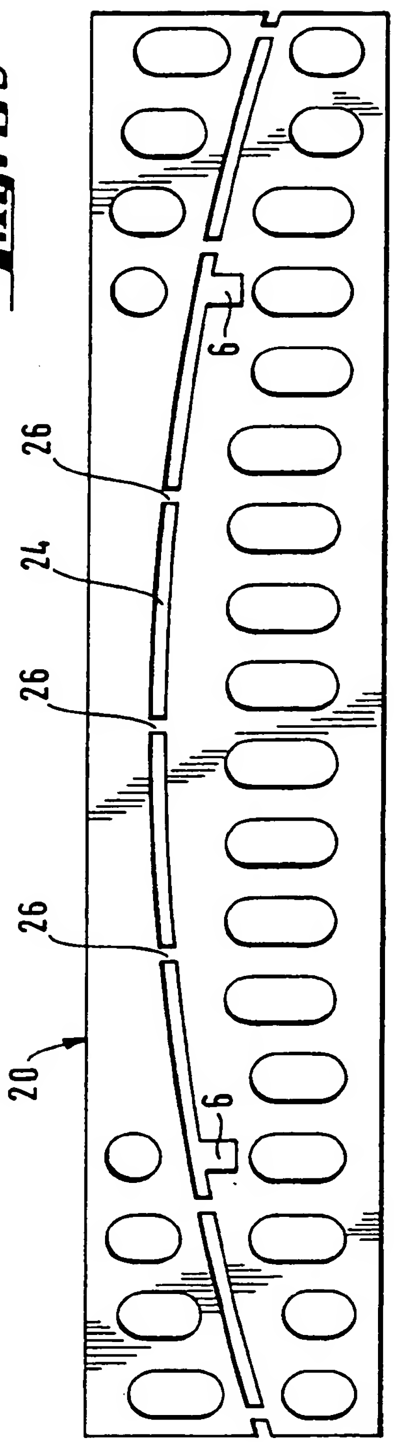

Fig. 3B

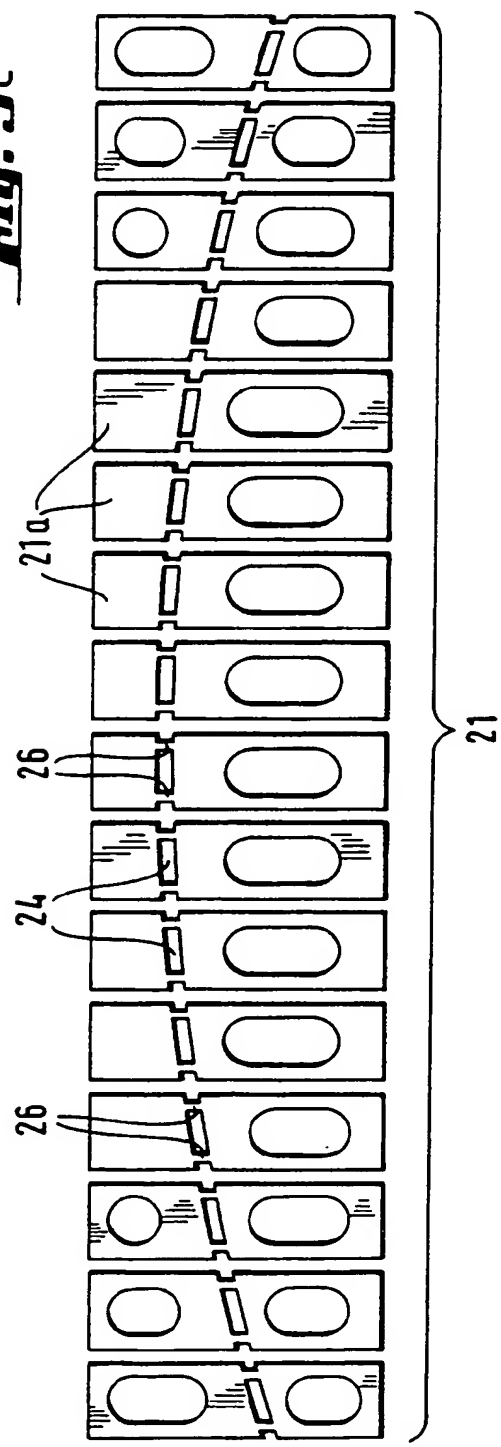

Fig. 3C

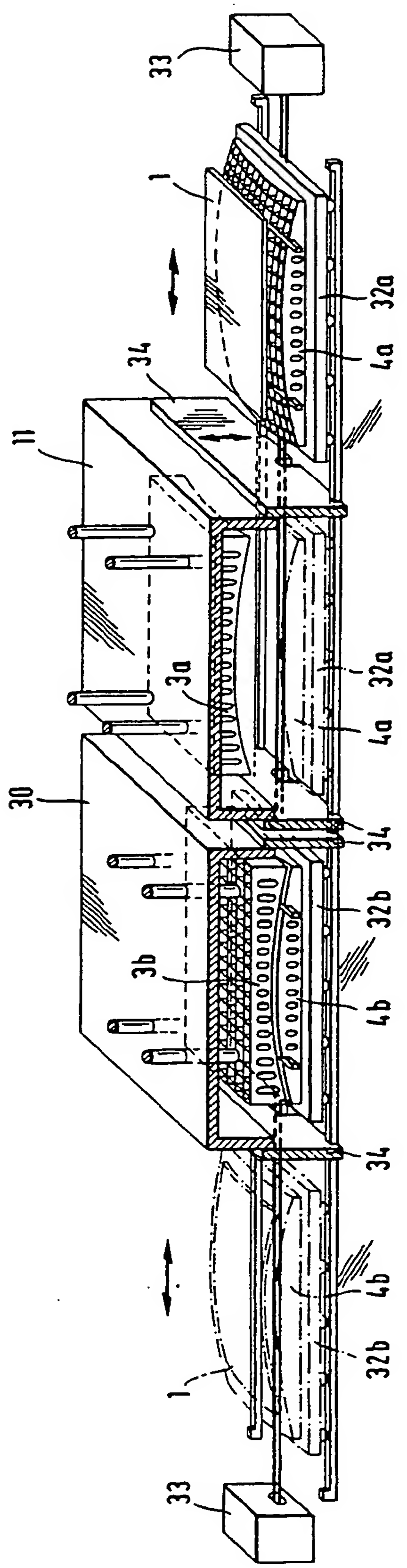

Fig. 4

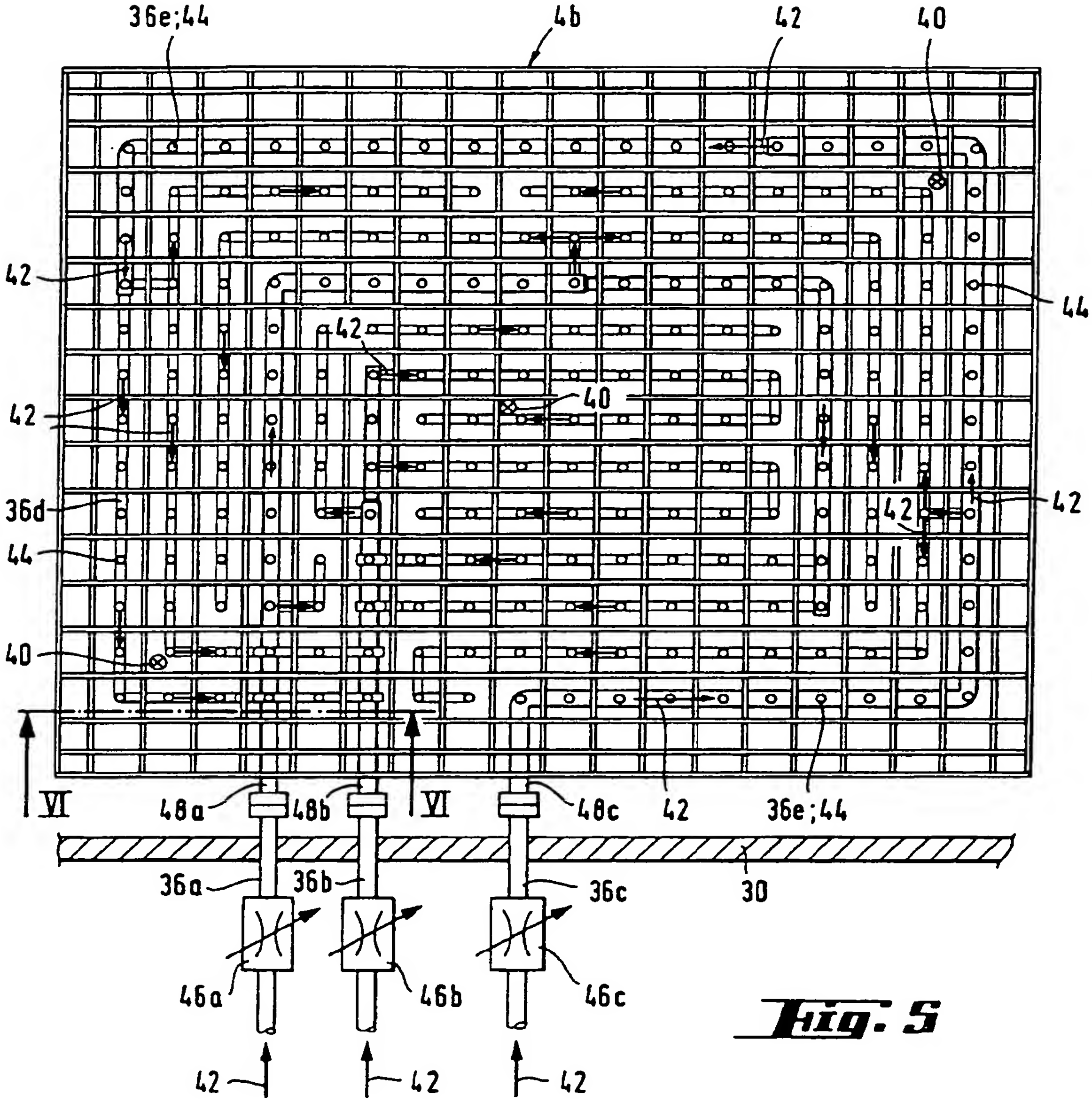
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Fig. 5

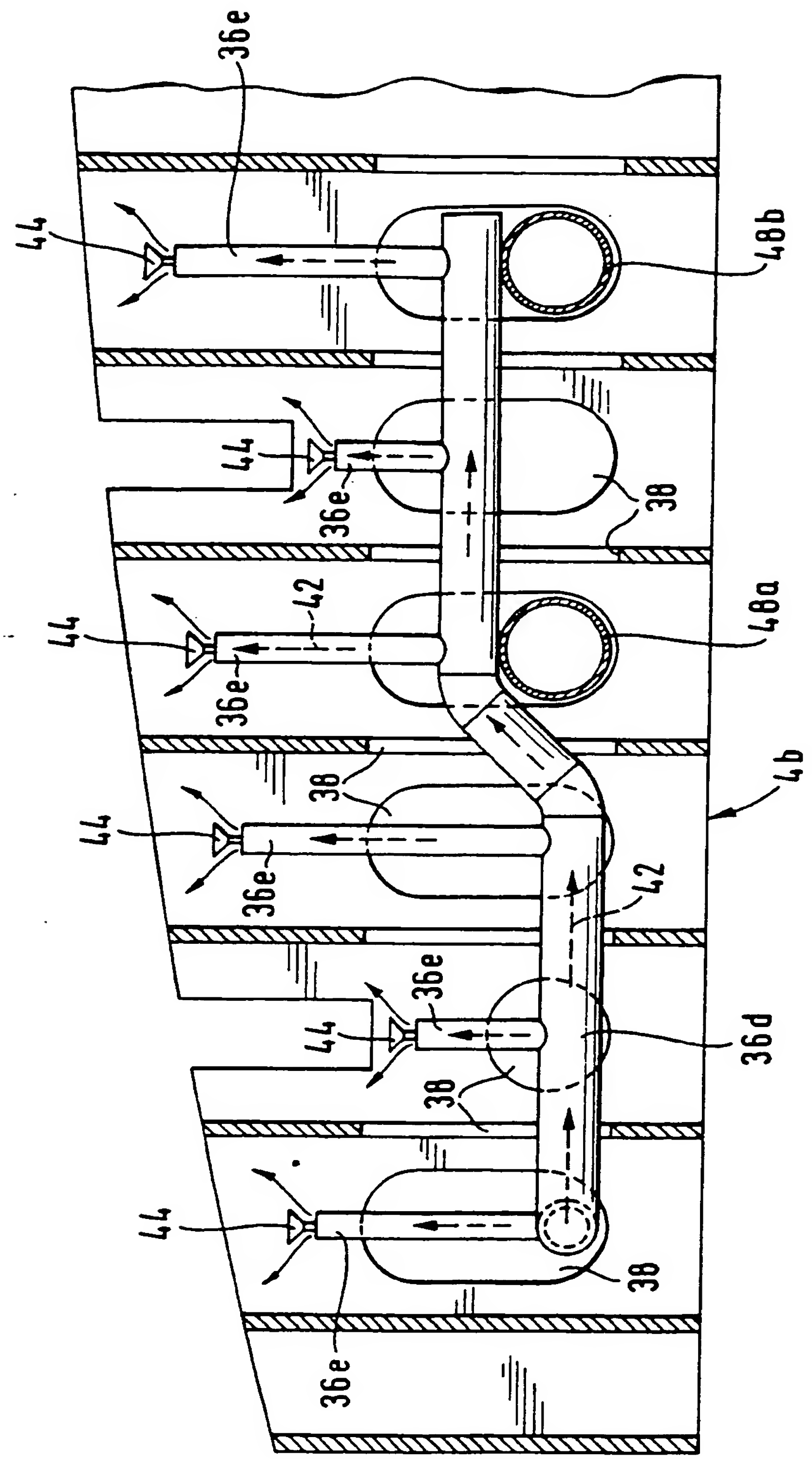

Fig. 6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 3681

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
D,X	US-A-3 938 363 (KELSEY) * claims 1-3,5; figures 1-5 *	1,2,5	B21D11/20
A	DE-A-2 822 825 (GENERAL DYNAMICS) * claims 1-4; figures 2-4 *	1	
A	DE-A-3 124 514 (BLOHM U. VOSS) * claim 1; figures 2,3 *	1	
A	US-A-3 745 805 (GAUTHIER) * claims 1-7; figure 1 *	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

B21D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	18 AUGUST 1993	SCHLAITZ J.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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